Geodiversity of the Lightning Ridge Area and Implications for Geotourism

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The Lightning Ridge region displays rich geodiversity. Though best known for its valuable black opal, it is also world-renowned for yielding a diversity of opalised fossils, including invertebrates, reptiles, dinosaurs and some of the earliest known monotreme mammals. Cenozoic silcrete preserves impressions of fossil plants in great detail at several sites. At Cuddie Springs, 100 km SSW of Lightning Ridge, remains of extinct Pleistocene megafauna are found in association with Aboriginal tools. Numerous Aboriginal sites are also scattered around the ridges and along waterways. Over 100 years of mostly small-scale opal mining at Lightning Ridge is evidenced by historic workings and equipment that are unique to this area or rarely seen elsewhere. This valuable record of geoheritage is of interest to tourists, historians, scientists and artists. Geotourism is intimately linked with opal-mining and is a growing source of income to the region, on par with documented sales of opal itself. Managing such a diverse region presents a challenge, as diverse stakeholders can have conflicting objectives. Tourism has the potential to unite stakeholders and ensure the prosperity of the region long after the opal resources are exhausted. A whole-of-government approach is vital in ensuring sustainable development and prosperity of the region.

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INTRODUCTION

Lightning Ridge lies 770 km northwest of Sydney, in northern New South Wales (Fig. 1). The remote town in Walgett Shire is best known for opal, Australia's national gemstone and the mineral emblem of New South Wales. The town also supports rich living cultural and industrial traditions which are related to opal mining and Aboriginal occupation. Its population of about 2600 (2006 census, Australian Bureau of Statistics) is highly variable due to transient miners and residents. Walgett Shire is bolstered by up to 70 000 visitors a year (Tourism Research Australia 2008) who come to try opal fossicking or to explore an outback mining town.

Opal was first discovered at Lightning Ridge in the 1880s but the importance of the discovery was not immediately realised. In about 1901 or 1902, local boundary rider, Jack Murray put down a shaft at Lightning Ridge and was soon joined by Charles Nettleton, who commenced a shaft and then sold the opals he found, thus attracting attention to the field (NSW Department of Mineral Resources 2000).

Governance of the area has been a challenge since. Opal mining in and around Lightning Ridge is generally small scale and there are currently about 3500 small claims registered. Due to the geographical isolation of the area, government regulation and management is often difficult. Theft of opal from claims ('ratting') and social problems occur in these remote and sometimes basic conditions. Conflict between miners and other local stakeholders is common. Whilst many, including farmers, environmentalists and safety regulators, would prefer that land be fully rehabilitated after mining, others (e.g. Smith 2007) argue that some workings should be left accessible or preserved for future exploration, research and geotourism.

GEODIVERSITY

Lightning Ridge is situated on the southern margin of the Great Australian Basin, one of the

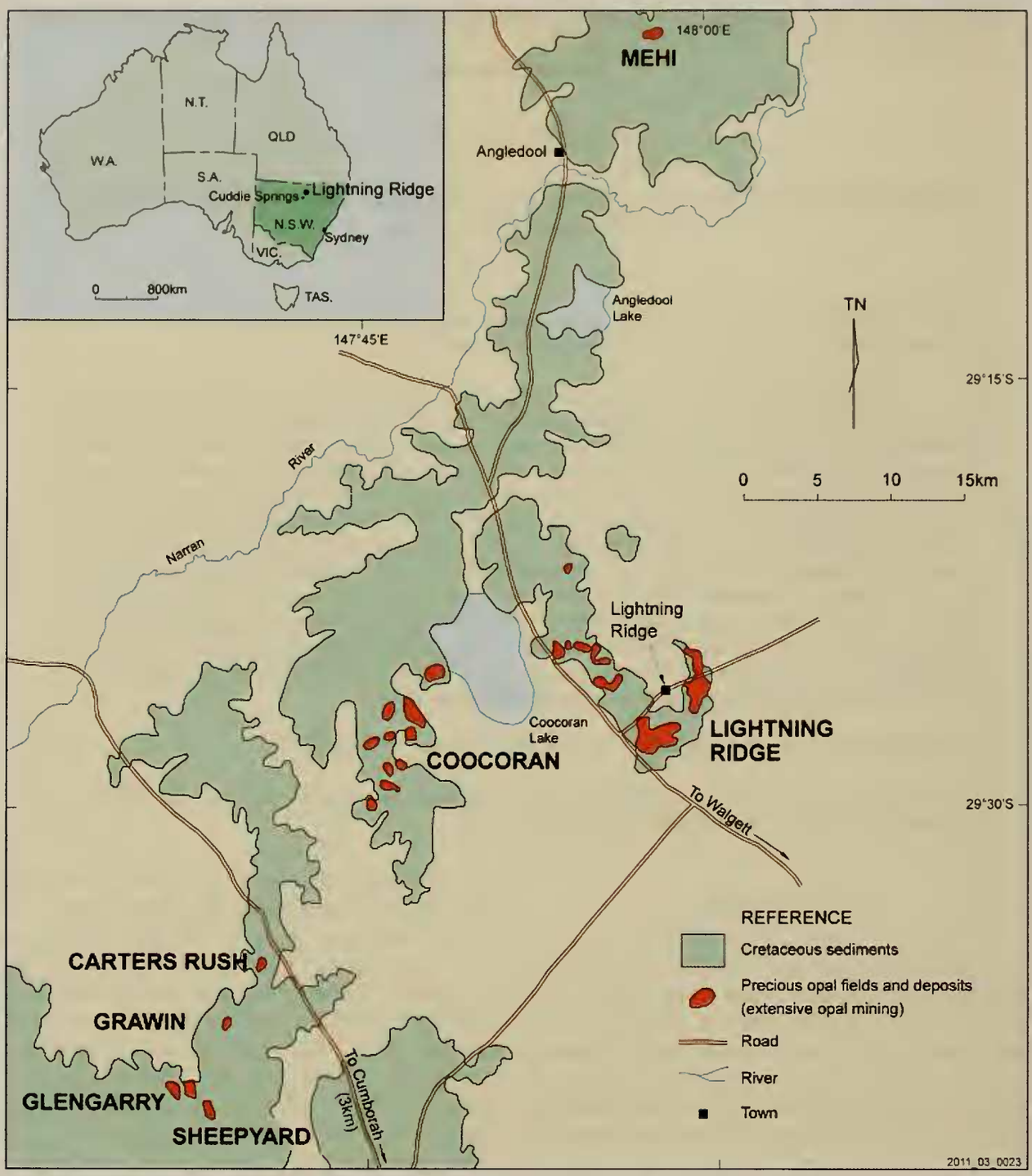

Figure 1. Locality map showing major opal fields in the Lightning Ridge area and simplified geology.

world's largest artesian groundwater basins, which contains Jurassic and Cretaceous fluvio-estuarine to marine sedimentary rocks and includes aquifers that provide a local water supply. The oldest exposed rocks in the area are Cretaceous, and they form north–northeasterly-trending low ridges. They are capped and protected by resistant plateaux of Miocene quartz-rich gravel and silcrete (Burton, in press). The ridges support scrubland and remnant native woodland and are flanked by broad colluvial slopes and grassy alluvial floodplains, which include lakes and aeolian features of Quaternary age.

The region exhibits unique and exceptional geodiversity and landscapes, shaped by over 100 million years of geological history. It is also the only place in the world to produce commercial quantities of extremely valuable black opal. Low ridges of weathered Cretaceous rocks of the Rolling Downs Group stand proud of an extensive Cenozoic floodplain, forming distinctive landscapes that exert

strong influence on faunal and floral distribution, and have been appreciated by the Aborigines for thousands of years. The traditional lands of the Yuwalaraay or Euahlayi people extend from Angledool in the north, to Walgett in the south, to the Birree and Bohkara rivers in the west (Narran Lakes Ecosystem Project factsheet undated). Many Aboriginal sites including shell middens, hearth sites with clay ovens, quarries, rock wells, fishing traps, scarred trees and burial sites remain around the region (Predavec et al. 2004).

Cretaceous stratigraphy and palaeontology

During the Cretaceous, Gondwana was at high latitudes, and continental fragmentation generated a series of rift and passive-margin basins that today preserve an impressive record of Mesozoic animal and plant remains (Dettman et al. 1992; McLoughlin and Kear 2010), such as those seen at Lightning Ridge.

The Cretaceous stratigraphy at Lightning Ridge was described by Byrnes (1977), Watkins (1985), and Smith and Smith (1999). The Lower Cretaceous Griman Creek Formation of the Rolling Downs Group is economically significant as it contains the opal fields of the Lightning Ridge area (Fig. 1). Based on palynology, the unit has been assigned an early to middle Albian age (Burger 1980; Morgan 1984). Following on from the work of Byrnes (1977), the Griman Creek Formation has been divided into two members; the uppermost Coocoran Claystone Member and the underlying Wallangulla Sandstone Member, including lenses of the 'clay facies'. The Coocoran Claystone Member (or 'shincracker') consists of white to cream claystone, which is commonly silicified to porcellanite. The Wallangulla Sandstone Member comprises fine- to medium-grained, pale, kaolinitic sandstone that is, in places, cross-bedded and iron-stained. Included lenses of 'Finch clay facies' generally consist of soft, grey to buff claystone. Opal occurs in the top 30 m of the Cretaceous rocks of the ridge country, generally in the top metre of the 'Finch clay facies' and beneath sandstone beds. It typically occurs as irregular nodules ('nobbies') as thin seams along vertical or horizontal joint planes, and as replacements and cast fillings after fossils. Surface structures appear to have influenced the distribution of some known opal occurrences, though conditions required for opal formation are not fully understood and still a topic of some debate. Burton (in press) summarises three main models for opal formation as: weathering processes with passive structural control (e.g. Darragh et al. 1976; Watkins 1985); upwelling fluids with active structural control (Pecover 1996, 1999; Rey et al. 2003); and biological processes. Behr et al. (2000) suggest that microbes may have played a role in opal formation.

Cretaceous rocks of the region are renowned for their diversity of rare opalised fossils (Fig. 2), which are summarised by Smith and Smith (1999). Lightning Ridge is unique among Australian opal fields in producing opalised fossils of predominantly freshwater and terrestrial plants and animals (Smith 2007; 2009) and is the only significant dinosaur locality in New South Wales. Many workers have described fossils from the area, including monotremes (Archer et al. 1985, Flannery et al. 1995, Musser 2005), crocodiles (Molnar 1980, Molnar and Willis 2001), bivalves (Hocknull 2000; Kear 2006), gastropods (Hamilton-Bruce et al. 2002; Hamilton-Bruce and Kear 2010), echinoderms, crustaceans, cartilaginous and bony fishes and lungfish (Smith and Smith 1999; Kemp and Molnar 1981), plesiosaurs, dinosaurs (Molnar and Galton 1986; Rich and Vickers-Rich 1994; Molnar 2010), pterosaurs, birds (Molnar 1999), turtles (Smith 2009; 2010), foraminifera (Scheibnerova 1974; 1984), plants (White 1986) and pollen (Morgan 1984). Appendix 1 lists over 60 fossil taxa that have been found as a by-product of mining operations.

Paleogene to Neogene deposits and fossils

Early Cretaceous rocks are unconformably overlain by Paleogene to Neogene gravels and pebbly to granule-bearing quartz-rich sands. Gravels include quartz, chert, jasper, petrified wood, topaz and agate. Palynological dating of Tertiary sediments from the Namoi River and Gwyder River valleys (Martin 1980) and the Castlereagh River valley (Martin 1981) indicated that Cainozoic deposition did not begin until the Middle to Late Miocene, and so Burton (in press) has interpreted the local gravels to be Miocene.

Much of the sediment has been silicified to silcrete, which Burton (in press) interprets as largely obscured by colluvium derived from the ridges. The timing of silicification events within the Cenozoic is problematic. Silcrete was used for tool-making by the Aboriginal population and tools and quarry sites are preserved in the region, as documented by Predavec et al. (2004).

Silcrete at Grawin has yielded a diverse macroflora assemblage of interpreted ?Oligocene to ?mid-Miocene age (Carpenter et al., in litt.). At Cumborah, approximately 40 km southwest of Lightning Ridge, fossil angiosperm leaf impressions in silicified very fine-grained sandstone (Fig. 3) were collected by the author and Burton (Burton, in press)

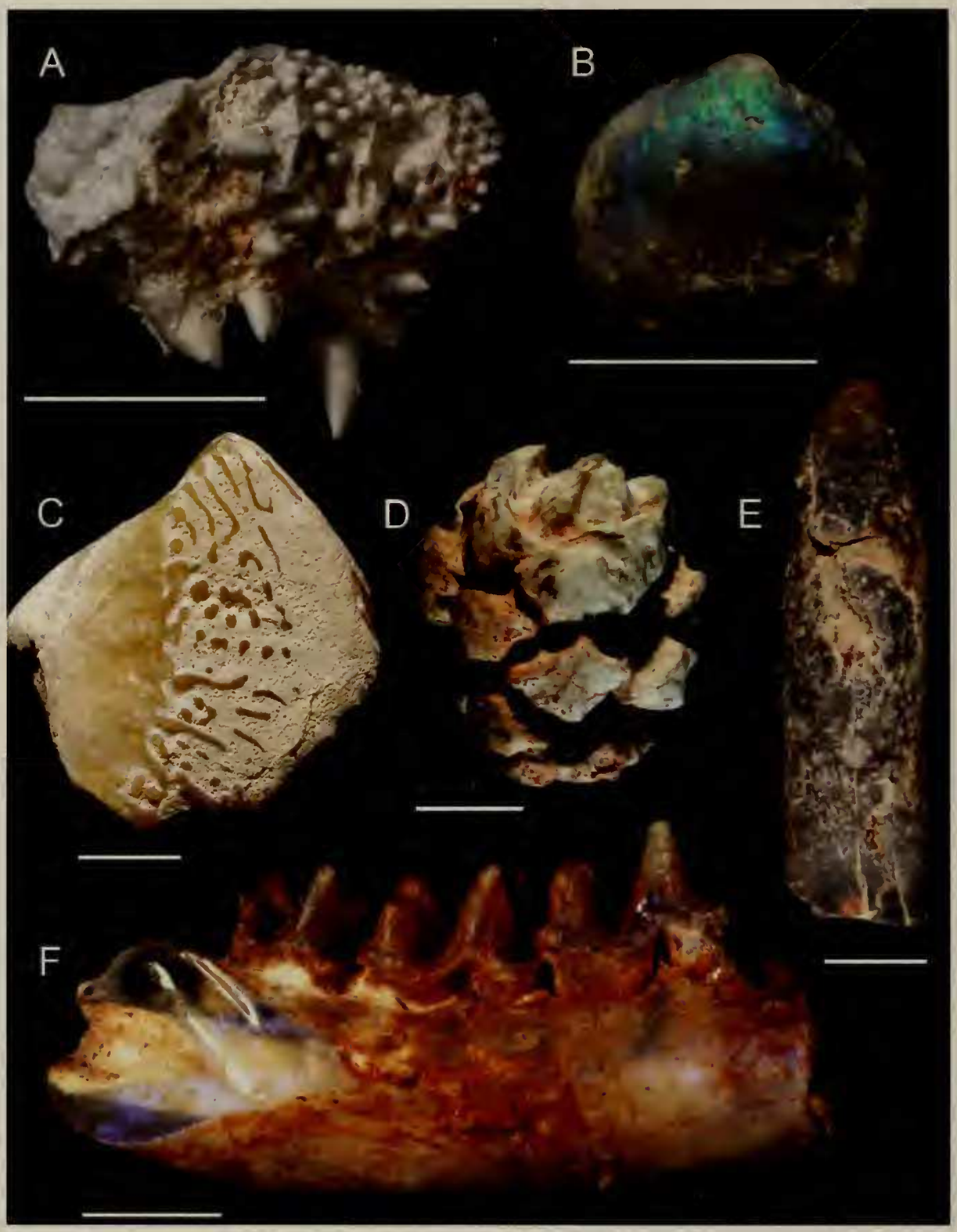

Figure 2. Early Cretaceous opalised fossils recovered from discarded surface dirt at Lightning Ridge. Fossils are from the collection of the Australian Opal Centre except C and F from the collection of the Australian Museum. A. Fish palate with finely-preserved, sharply-pointed teeth. B. Corbiculid bivalve, one of the smallest and most rare bivalve taxa in the Lightning Ridge fauna. C. Turtle shell fragment with ornamentation. D. Pine cone with scales dessicated prior to fossilisation.E. Sauropod dinosaur tooth. F. Lower jaw fragment of the monotreme mammal *Steropodon galmani,* one of the most significant fossils ever found in Australia, featured on the cover of the journal Nature. Scale bar = 5mm. Photographer Robert A. Smith. Photographs and caption courtesy of the Australian Opal Centre.

Figure 3. Angiosperm leaf impression — a broad-leaved dicot showing pinnate semi-craspedodromous venation. (Photographer: Simone Meakin).

from the base of a gravel pit. The fossils are difficult to date and could be Cenomanian or younger, but an age of Paleocene to Miocene age is likely and they are suggestive of vine forest (pers. comm., David Greenwood, Brandon University, Manitoba, Canada). Taylor (1978) estimated the age of the gravels at Cumborah to be Late Miocene.

Quaternary features

Adjacent to the ridges, broad floodplains have been built up through the Cenozoic by evolving fluvial systems that are described by Taylor (1976, 1978), Watkins and Meakin (1996) and Burton (2010). Aeolian redistribution of sediments has formed lunettes on the eastern margin of ephemeral water bodies, and source-bordering dunes (Watkins and Meakin 1996; Burton 2010). The history of fluvial deposition and associated geological, geomorphic and vegetative features in the Walgett region are described by Watkins and Meakin (1996). Following on from that work, the late Pleistocene to Holocene fluvial sequence on the plains surrounding the ridge country has been mapped by Burton (in press) as the Bugwah Formation and Marra Creek Formation. The Bugwah Formation preserves wide, slightly elevated meander plains and sinuous channels and has an estimated age of 13400 to 6400 years BP (Watkins and Meakin 1996). The Marra Creek Formation contains narrow channels and meander belts that are not elevated, and the unit represents deposition from 6400 years BP to the present day.

The Narran Lakes Nature Reserve, centred 60 km northwest of Walgett, was listed as a UNESCO 'Ramsar' Wetland of International Importance in June 1999 as it is considered an excellent example of a relatively undisturbed terminal lake system (listed as Site 5AU053 at www.wetlands.org/RSIS). It contains many Aboriginal sites including shell middens, hearth sites with clay ovens, quarries, rock wells, scarred trees and burial sites (Narran Ecosystem Project, undated fact sheet). Springs, waterholes and bends in the Narran River feature in local Aboriginal lore as part of the dreaming path of Baayami, a creation being who created the landscape's natural features.

Angledool Aboriginal Reserve and Cemetery are included in the Australian Heritage Database maintained by the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (http://www.environment.gov.au/heritage/ahdb/index.html). An artesian bore bath at Lightning Ridge, one of three in Walgett Shire, is also listed in the Australian Heritage Database(http://

Figure 4. Aerial shot taken in 1994 showing opal workings in the Preserved Opal Fields. Underground mining is evidenced by mullock heaps stored on the ground surface, and part of the historic Western Fall open cut mine can be seen at the top of the photograph. (Photographer: Dave Barnes; Industry & Investment NSW photographic library).

www.environment.gov.au/heritage/ahdb/index.html). The bore was sunk to a depth of over 1 km in 1962 and taps geothermally heated artesian water that is confined and pressurised within aquifers of the Great Australian Basin and flows freely to the surface at a temperature of about 41.5°C.

At Cuddie Springs, approximately 100 km south–southwest of Lighting Ridge, a diversity of megafauna bones, including marsupials (e.g. *Diprotodon*), birds and reptiles, is preserved in an ephemeral lake, along with Aboriginal stone tools, charcoal and pollen. The deposit is interpreted by some (e.g. Field and Dodson 1999; Field, Wroe and Fullagar 2006) to indicate the local coexistence of megafauna and humans at the site, whereas others (e.g. Brook, Gillespie and Martin 2006) argue that humans caused the extinction of the megafauna and suggest that the deposit has been at least partly sourced from further afield during flooding. Regardless, the site remains an important focus for research into the extinction of Australian megafauna.

GEOTOURISM

Apart from the landscape and geological features described above, the small-scale mining culture, technology and the miners themselves are unique and of great interest to tourists. Popular tourist attractions include the historic Lunatic Hill open cut mine, underground mine tours, an opal and fossil centre, opal field tours, a self-guided tour of the opal fields which uses car doors as signposts, a fossicking site at the tourist office, opal and fossil shops, art galleries, quaint buildings made of local stone and numerous historic and cultural mining sites and buildings. Hot artesian bore baths also attract visitors to the town, and the prehistoric Cuddie Springs site occasionally has open days organised by researchers and the Walgett Shire Council.

The Australian Opal Centre (AOC) attracts thousands of visitors to its showroom each year and is involved in ongoing research. The ARC Linkage Grant project 'Mesozoic Austral Biodiversity: Research and Regional Museum Applications' involves museums and universities in NSW, Victoria, Queensland, South Australia and Sweden in partnership with the AOC. The research focuses on Mesozoic biodiversity, palaeoenvironments, palaeoclimate, and fossil-based tourism. The AOC also produces the newsletter *Harold Hodges' Opal Teeth* to promote geoscience and tourism in the region. Such ecologically sustainable development should be a vital component of the management of the opal fields.

Geoheritage

Opal mining landscapes (Fig. 4) include many features of heritage and cultural interest. Brammall and Smith (2007) describe local examples of hand-dug shafts, puddling dams, tailing heaps, silt tanks, hand-made camps and historic or unique machinery such as agitators, dry rumblers and hoists. Nettleton's Shaft, sunk in Lightning Ridge in 1903, is in the Australian Heritage Database. Mining methods have gradually evolved in the opal fields to adapt to local mining conditions but have generally changed very little over the last hundred years (Figs 5 a,b). Idriess (1944) gives a vivid historic account of the mining lifestyle.

The Preserved Opal Fields around Lightning Ridge have been gazetted in recognition of the heritage and scientific significance of those areas. Covering approximately 63 sq km based over 5 non-contiguous zones, including the Three Mile Opal Field and Lunatic Hill open cut, they contain relics from a century of small-scale mining activity and have yielded an abundance of opal and fossils. These areas

Figure 5. Top: Historical opal working. Miners who were down on their luck were allowed to fossick on other miners' tailings, using devices such as the 'snippers' held by the man on the left. Bottom: Using a dry rumbler in 1994 to search for opal in top dirt dumped by miners in earlier times. (Industry & Investment NSW photographic library).

are now the only remaining areas where miners are allowed to reside permanently in camps on their 20 year Western Lands leases. The Preserved Opal Fields concept has been endorsed by a range of stakeholders as it allows sustainable, low-impact geotourism. However, conflicts exist between mining heritage and rehabilitation and safety objectives, as many old workings pose risks. Moreover, numerous important heritage and scientific sites lie outside these areas. A Crown Reserve was created in 2009 over parts of the Preserved Opal Fields for opal mining and residential purposes and is to be administered by a trust.

DISCUSSION

Local geological features and associated mining activity are clearly prime tourist attractions in the Lightning Ridge area (Table 1). Together, mining and tourism significantly support the local economy (along with agriculture) and supply employment for almost a quarter of the local population, as supported by data from the Australian Bureau of Statistics (2006). Tourism brings opal buyers and wealth to the region, and mining activity supplies the minerals, fossils, characters and landscapes that attract them. Palaeontologists consult with opal miners to see what they have found, or to access spoil heaps and opal mines. Without the assistance of miners, many fossils would never have been recognised and smaller and less spectacular fossils would tend to end up in tailings and silt tanks (Smith 2007). Hence, collaboration between miners and researchers is vital for fossil discovery.

Over the last decade, mining activity and the estimated value of opal recovered have declined (Fig. 6), whereas tourist visitation to the town has increased (Fig. 7). The relationship between tourism and opal mining has evolved into a symbiotic relationship. If these trends continue, it is vital for the town's prosperity that both tourism and opal mining be sustained. The establishment of a 'Geopark' at Lightning Ridge was suggested by Turner (2006a) and also investigated by the Australian Opal Centre. Turner (2006b) cautioned that the boundary would have to be well drawn to accommodate Geopark rules regarding the buying and selling of the material that they wish to promote. The concept of a 'Geopark', as discussed by Turner (2006b) could provide a framework in which the local community, including the Aboriginal population, could sustainably manage and promote their geological and cultural heritage, thus boosting the local economy. The Australian Government has however expressed concern about the application of the UNESCO Geopark concept in Australia and concluded that existing mechanisms

Table 1. A summary of geotourism features of the Lightning Ridge region

- Black opal and the opal-mining industry
- An authentic outback mining town surrounded by opal-mining landscapes
- Small-scale mining methods in use, living heritage
- A huge diversity of opalised Cretaceous fossils, especially vertebrates
- Prehistoric sites (e.g. Aboriginal, megafauna)
- Historic sites (e.g. buildings, camps, machinery, signposts, hand-dug shafts)
- Artesian baths
- Underground and surface tours, community fossicking heap, self-guided car door tour, opal and fossil displays and shops, galleries and studios

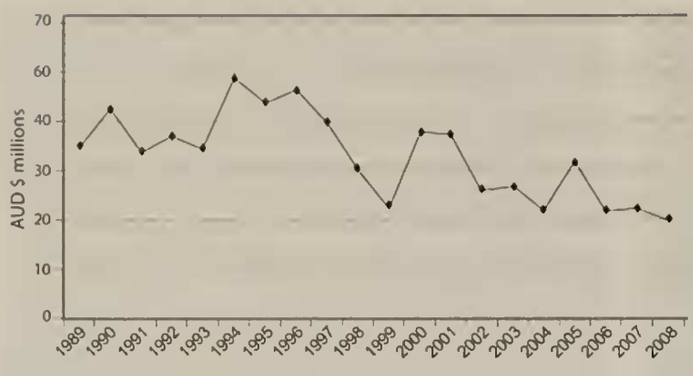

Figure 6. Value of opal exports from NSW, 1989–2008. (Source: DFAT STARS Database; consistent with ABS Cat No 5368.0, September 2009 data).

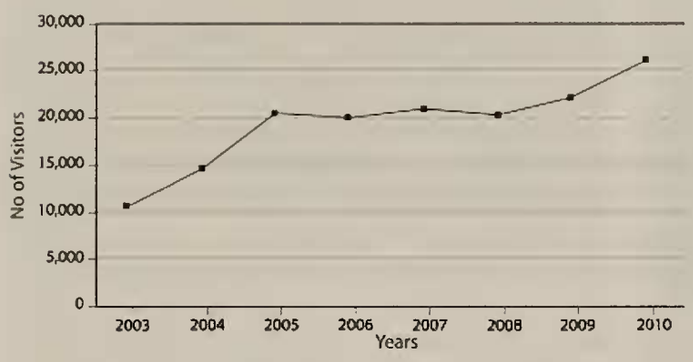

Figure 7. Visitor numbers to Lightning Ridge Visitor Information Centre.

are sufficient to protect geoheritage in Australia (Environmental Protection and Heritage Council, 2009). It has requested that UNESCO take no further action to recognise potential Australian Geoparks unless the formal agreement of the Australian Government has been provided first.

Geotourism, particularly the controlled access to fields by tourists, offers a possible solution to some of the region's problems by providing common ground that has the support of many stakeholders. It benefits all the community by providing income and jobs, and results in improved services and facilities. It educates and encourages commercial and research partnerships. A healthy tourist industry ensures prosperity of the region in hard times, such as drought and flood. Together with mining, tourism can promote ecologically sustainable development by respecting cultures, contributing to conservation of biodiversity, influencing land-use planning, communicating, educating, and contributing to the social and economic development of the community.

CONCLUSIONS

Lightning Ridge is unique in many respects but most notably for its remarkable opal and fossils. Its diverse geological features provide a rare insight into Australia's Cretaceous palaeogeography, palaeoclimate and extreme biodiversity. The fossils contribute greatly to our understanding of Early Cretaceous freshwater and terrestrial biota and environments. To enable continued discovery and research, palaeontologists must continue to work in close collaboration with opal miners, and also provide support to local geotourism initiatives.

Promoting regional development is seen as an important target by government. Given their symbiotic relationship, the tourism and opal mining industries must both be sustained to ensure the future prosperity of the area. A sustainable, low-impact, high-yield growth in tourism is necessary to support the region's development and to counteract a potential decline in opal discovery. A Whole-of-Government approach to the management of this diverse area, involving many state and federal agencies, is vital to ensure its long-term environmental, economic and social sustainability.

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APPENDIX. List of Cretaceous fossil fauna of the Griman Creek Formation, Lightning Ridge, from Smith (2007, 2009, 2010), with contributions from other sources (p.c. = pers. comm.).

		Taxon	Source
Chlorophyceae	Charophyta	indet. taxon	Dr Adriana Garcia p.c; Henk Godthelp p.c.
Foraminifera		*Hyperammina* sp	Scheibnerova 1984
		Ramulina tetrahedralis Ludbrook 1966	Scheibnerova 1984
Radiolaria		? radiolarian	Scheibnerova 1984
Polychaeta		indet. taxon	
Mollusca	Pelecypoda	*Alaythyria jaqueti* Newton 1915	
		Megalovirgus wintonensis Hocknull 1997	
		Hyridella macmichaeli Hocknull 1997	
		Hyridella (Protohyridella) goondiwindiensis Hocknull 1997	
		Palaeohyridella godthelpi Hocknull 2000	
		Coocrania hamiltonbrucei Kear 2006	
		large ?hyriid	
		sphaeriid	
		'tellen' or nut shell	
		corbiculid – river pea shell	
		strongly ridged, subcircular unioid	
		clam with spines, narrow rippled margins	
	Gastropoda	*Albianopalin benkeari* Hamilton-Bruce et al. 2002	
		Albianopalin lizsmithae Hamilton-Bruce et al. 2002	
		Notopala sp. Hamilton-Bruce et al. 2002	
		Melanoides godthelpi Hamilton-Bruce et al. 2004	
		Fretacaeles gautae Hamilton-Bruce and Kear 2006	
		Suratia marilynae Hamilton-Bruce and Kear 2010	
Crustacea	Decapoda	freshwater crayfish – indet. taxon	
Anura		frog – indet. taxon	Dr Mike Tyler and Henk Godthelp p.c.
Pisces	Chondrichthyes	small shark cf *Isurus* or *Cretolamna*	small shark cf *Isurus* or \ *Cretolamna*
	Actinopterygia – Teleostei	indet. taxa x 4	Dr Sue Turner pers. comm.
		aspidorhynchid cf *Richmondichthys sweeti* Etheridge and Smith Woodward 1891	

		Taxon	Source
		freshwater eel – indet. taxon	Dr Peter Forey and Dr Tom Rich p.c..
	Dipnoi – lungfish	*Ceratodus wollastoni* Chapman 1914	Kemp and Molnar 1981
		Ceratodus diutinus Kemp 1993	Kemp 1993
		Neoceratodus forsteri Krefft 1870	Kemp and Molnar 1981
Ichthyosauria		ichthyosaur - indet. taxon	Dr Benjamin Kear p.c.
Sauropterygia	Pliosauria	?Leptocleidid pliosaur	Dr Benjamin Kear p.c.
	Plesiosauria	elamosaurid plesiosaur - indet. taxon	Dr Benjamin Kear p.c.
Testudines - turtles	Chelidae	indeterminate chelid pleurodires x 2 taxa	Smith 2010
	Testudines indet.	meiolaniid-like taxon 1 - 'Spook's Turtle'	Smith 2009
		meiolaniid-like taxon 2 - 'Sunflash Turtle'	Smith 2009
Crocodilia		*Crocodylus selaslophensis* Etheridge 1917	
		crocodile – ziphodont	Molnar and Willis 2001
		crocodile – conical tooth form	Molnar and Willis 2001
Pterosauria		pterosaur - indet. taxon	Henk Godthelp p.c.
Dinosauria	Ornithopoda	stegosaurid	Dr Benjamin Kear p.c.
		Muttaburrasaurus sp	Molnar 1991, 1996
		Fulgurotherium australe von Huene 1932 (Molnar and Galton 1986)	
		Atlascopcosaurus loadsi Rich and Rich 1989	
		Leallynasaurus sp? Rich and Rich 1989	
		very large hypsilophodontid	very large hypsilophodontid
	Sauropodo-morpha	indeterminate sauropods x 2 - 'spoon tooth' form, 'sharp tooth' form	
		small ?prosauropod	
	Theropoda	*Rapator ornitholestoides* von Huene 1932	
		? alvarezsaurid or ceratosaurid - very large form	
		dromaeosaurid cf. *Velociraptor*	Henk Godthelp p.c.
		ornithomimosaurid	Henk Godthelp p.c.
		? spinosaurid	Dr Benjamin Kear p.c.
	Aves	unidentified ornithoracines - two taxa	Molnar 1999
Mammalia	Synapsida	unidentified ?synapsid	Clemens et al. 2003
	Monotremata	Steropodontidae - *Steropodon galmani* Archer et al. 1985	
		Kollikodontidae - *Kollikodon ritchiei* Flannery et al. 1995	
		?Ornithorhynchidae - up to 3 unidentified taxa	Smith 2009